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The photon exhibits dualism, constant velocity and nonlocality: What do they have in common?

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ABSTRACT

The photon is typically regarded as a unitary object that is both particle-discrete and wave-continuous. This is a paradoxical position and we live with it by making dualism a fundamental feature of radiation. It is argued here that the photon is not unitary; rather it has two identities, one supporting discrete behavior and the other supporting continuous (wave) behavior. There is photon kinetic energy that is always discrete/localized on arrival; it never splits (on half-silvered mirrors) or diffracts (in pinholes or slits). Then there is the photon's probability wavefront that is continuous and diffractable. Acknowledging that the photon has two identities explains the photon's dual nature. And wave-particle duality is central to quantum mechanics. Understanding it leads to new insights into the photon's constant velocity and its entanglement with another photon.

1. Container physics

The relation of a material object to space (and to time) doesn't get much attention these days. Newton and Leibniz got into a famous dispute [1] about space with Newton regarding space as a container that hosted material objects, while Leibniz dismissed hosting and regarded space as the set of relations between objects. Modern physics seems to favor Newton's container theory at least to the extent that space is seen as the arena wherein material objects operate: move, decay and reside. Time is also necessary for material objects; to exist requires progression (persistence) in time. Space container physics then is the view that physically real objects (entities) reside in and occupy space while progressing in time.

Space container physics works well for material particles, but less well for radiation. A particle stationary relative to some reference point has a defined location in space. If it moves it has a defined trajectory. An in-flight photon never has a defined space location nor a trajectory.

We live in a world of space and existing material objects and it is possible we have defined our physics accordingly. It may be useful to reframe our analysis to make it neutral between existence and occurrence, between space and time. This requires a switch from object to "entity" and from space-or-time to "dimension."

In formal terms, an entity is something physically real (i.e., of mass or energy) that has a presence in a dimension. Given the equality of mass and energy ($E = mc^2$) and the equality of space and time (relativity), a broad view of entity seems appropriate. At least in theory, an entity may reside in time just as an entity resides in space. By the same token, entities may be of (rest) mass or (kinetic) energy and have a presence in space or time respectively. Perhaps there is a time container physics along side of space container physics.

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If time is to be a container, the entities contained must be free of space-occupying rest mass. This leaves us with occurring radiation; its frequency cycles require time just as material objects require space. Space then is the container/arena for quantized matter while time is possibly a container/arena for quantized radiation (photons).

It is best to focus on entities that do not combine rest mass with energy since that combination brings in more complexity. That leaves us with two "simpler" entities: inertial rest mass (of space) that has no kinetic energy; and radiation energy (of time) that has no rest mass. They are in contrast to matter-in-motion which is a "mixed" entity, having both rest mass and kinetic energy. Mixed entities (and mechanics) have been covered elsewhere [2]; they are not of concern here.

2. Dualism

There are two universal (and unreflective) assumptions made about the photon. First, by naming it we think of it as a single, unitary object; and in space. Second, because a photon delivers its energy and momentum to a point on a material detector, we take this as proof of the photon's particle nature. Both assumptions are unfounded.

The photon is not a unitary object with contradictory features, wave versus particle. The photon actually has two related identities spanning two dimensions. This is evident from how the photon interacts with space devices. When a photon enters a slit or pinhole its probability-of-reception waves diffract to follow multiple paths, but photon energy is unaffected and always arrives undivided at reception. One photon identity is following paths in space and the other is not.

Work done on a charge constitutes kinetic energy which we know as radiation. The original (19th century) concept of kinetic energy had it being a quantitative property possessed by moving rest mass. This concept doesn't work well for radiation. First, radiation has no rest mass to support a property, Second, radiation occurs and its energy's oscillatory nature ($E = hf$) is hard to reconcile with a simple, passive property. Potential (latent) energy is possessed by rest mass, but kinetic energy acts on rest mass; kinetic energy is something unto itself; it is not the property of something else. This is why we have two conservation laws: that of energy and that of mass.

Oscillatory radiation energy is a physical entity just as is rest mass, its $E = mc^2$ equal. Just as rest mass resides in the space dimension, so radiation energy resides in the time dimension. Radiation energy is never split by space devices (slits, pinholes) because entities in general can only be divided in the dimension they occupy (reside in). Rest mass cannot be divided in time because it does not reside there. Photon energy cannot be divided in space because it does not reside there. Photon energy resides in time.

2.1. Photon identities

A photon's essential identity is its kinetic energy residing in time. This energy is pure oscillation, the cycles of which require time and hence reside there. This oscillation is created by the work done accelerating a charge. Doing work creates something physically real that is immaterial, active/oscillatory and time-residing.

A photon's second, potential, identity is its probability-of-reception waves that expand and rarefy while traveling in space at the speed of light. These waves can be regarded as the latent, space expression of the photon's time-residing energy. These waves: 1) are related to photon energy via $E = mc^2$; and 2) govern photon energy release in the aggregate (Box 1).

2.2. Photon not a particle

Being in time makes photon energy orthogonal to that which receives it, namely rest mass in space. Photon energy and a rest mass target reside in different dimensions and can only interact via a point event (reception) that is discrete for both space and time [3]. Energy and momentum then are delivered at this point event as the junction between what occurs in time with what exists in space.

Box 1
Sidenote.

Entities occupying an interval (residing) in one dimension are still available to the opposite dimension via an event. Your desk's rest mass resides in space, not in time; but its mass is always available for interaction events over time, e.g., you using your desk. Photon oscillation energy cycles reside in time, not in space; but this energy is always available for interaction events over space, e.g., reception on a material detector. Events combine kinetic energy and rest mass. You cannot access your desk without an event (of perception or touching); you cannot access photon energy without an event (reception on a detector).

Your desk in space has no defined location in time; only its interaction events do. Photon energy in time has no defined location in space; only its interaction events do. As a (main) branch of physics, mechanics expects an object/entity to have a defined space and time location. Mechanics doesn't work for the photon (no defined space location), or for your desk (no defined time location); mechanics covers a subset of physically real entities.

The concept of the photon traversing space as a packet of energy with a trajectory is our misinterpretation of radiation as space container physics (i.e., as mechanics).

There is no justification for comparing photon reception with particle impact simply because they are both point events; this comparison is a metaphor, not an explanation. With photon energy in time, the photon-as-particle concept sustaining dualism is eliminated.

- A photon has its energy in time while its probability waves progress in space.
- A photon does not have a particle character; it is not dualistic.

2.3. The double slit and the interferometer

2.3.1. Double slit

When a photon enters a double slit its time-residing photon energy is unaffected. Meanwhile the photon probability-of-reception waves pass through both slits and interfere. These waves carry no energy and are the photon's potential identity. They continue on in space toward a screen that blocks their passage. At one, random point on the screen, a photon reception event is triggered. Reception removes photon energy from time; this causes all of the waves to collapse as these waves owe their sustaining occurrence to time-residing energy. Photon energy from time is delivered to a target in space via an event that is discrete for both space and time.

2.3.2. Interferometer

When a single photon enters the first beam splitter of an interferometer, time-residing photon energy is once again unaffected. But photon probability-of-reception waves split and follow the two arms of the interferometer at 50% intensity. What travels the two arms is physically real since it can be divided or redirected in space. If both arms are blocked by detectors, only one detector will register the photon while the waves on the other arm collapse without a trace. This leads to the incorrect assumption that the photon chose only the path where its energy registered.

The classic case of interferometer misinterpretation is that of John Archibald Wheeler and his delayed choice experiment [4]. He argued that the photon "made a choice" – wave or particle – at the first beamsplitter; a choice that a subsequent measurement could retroactively determine. Wheeler's flawed assumption (photon as unitary object) renders his conclusion, (of retrocausality) suspect.

3. Constant velocity

If the photon is a packet of energy moving particle-like through space, then its velocity will differ for different inertial systems. The same is true if the photon is a wave disturbance of a "stationary" aether; observers with different velocities relative to the aether will disagree about the velocity of light. Both of these options have not survived experimentation; they are the result of applying space-container, rest-mass mechanics to massless radiation.

With a photon's energy residing in time, what remains to function (progress) in space are two immaterial, occurring, rarefying waveforms: EM waves and probability-of-reception waves. Both are subject to instantaneous collapse regardless of extent since as occurrences they depend upon photon energy in time; they have a single, orthogonal point of failure. EM waves permit our airborne communications; probability-of-reception waves govern probable photon termination on a target. The photon's probability-of-reception wavefront progresses in space at the speed of light without carrying photon energy with it.

Both waves have a constant *phase* velocity of wavelength multiplied by cycle frequency. The phase of a wave is any characteristic part (e.g., a wave crest); its travel for some distance in unit time is the wave's phase velocity. An observer moving toward the photon source will diminish both the wavelength and the cycle time (period) in equal proportions. A diminished wavelength means wave crests cover less distance per cycle; but diminished cycle period means an individual wave crest registers more quickly for the observer. The velocity of individual wave crests has not changed due to observer movement. The result is constant phase velocity; the same result obtains if the observer moves away from the photon source and measures an increase in wavelength but a decrease in frequency.

While the phase velocity stays the same, the wavelength change means a momentum change; similarly, the frequency change means both an energy change and change for the color of visible light. Observers in different inertial systems will measure different energy levels for light from the same source. This reflects the work done by, and velocity of, each inertial system relative to the photon source.

Einstein's second postulate – the speed of light as constant – was a positive contribution in 1905 when so little was known about radiation. It made the constant velocity of light a feature that didn't require explanation. But putting photon energy in time allows one to recognize that "photon velocity" is simply phase velocity. Immaterial wave crests reach you at a rate of wavelength times frequency and your velocity relative to the source doesn't change that rate. Photon constant velocity is a straightforward wave feature. And a postulate is not needed to enunciate an explicable feature.[1]

Radiation is the delivery of energy from one space location to another. We know that photon energy always reaches us at a constant velocity and that no space device can fractionate it. These two facts are the best indication we have that photon energy does not reside

[1] Einstein always recognized his postulate as a bit ad hoc. The constant velocity of light was a conundrum because everyone thought of velocity in terms of mechanics: an object moving through space or a (wave) disturbance of a material medium.

in, or navigate, space; photon energy must reside in time.[2] It leaves space progression to its (potential) wave identity.

4. Entanglement

Entangled photons received far apart from one another appear to coordinate their spins instantaneously, i.e., nonlocally. We have no explanation for this because we continue to regard the photon as a particle: a unitary object functioning/residing in container space.

4.1. Bonding in space and bonding in time

Space container physics and time container physics have equal standing and their hosted entities have parallel functions. Hence entities of mass or of energy are able to entangle (bond) in the one dimension wherein they reside; rest masses contained and bonding within space, photon energies contained and bonding within time.

For rest mass quanta, space as container allows two existing, space-residing quanta (particles) to entangle (bond) providing they are space adjacent. A sodium ion bonds with a chloride ion to yield salt. For photon energy quanta, time as container allows two occurring, time-residing quanta to entangle (bond) providing they are time adjacent. Two photon energy quanta are adjacent in time if they are the product of the same event, namely parametric down-conversion, wherein one high energy photon splits into two lesser photons, typically in a crystal [5].

4.2. Spin coordination for entangled photons

A high energy photon enters a crystal and splits into two lesser, entangled photons with different frequencies, blue and green in color. Energy and momentum are conserved in the splitting. Photon spin, normally one for a photon, is zero for the bonded pair as the two spins, right and left, cancel each other. The oscillations (energies) of the bonded photons are in time while their respective potential, probabilistic wavefronts expand in space.

Eventually the blue photon's wavefront triggers reception on an observer's detector at point A in space. Reception requires blue photon energy to leave its time entanglement, and in doing so, it acquires a right circular spin of one. Green photon energy simultaneously acquires a left circular spin of one, thereby conserving original total angular momentum of zero. The coordination of spin between blue and green photons is simultaneous because both photon energies are massless occurrences, adjacent/bonded in the time dimension.

At some distant point B in space the green photon's wavefront initiates termination and this observer records a left circular spin. The two observers compare measurements and agree that green photon spin at point B was defined well before any speed-of-light signal could have arrived from blue spin definition at point A. The two observers conclude, mistakenly, that spin coordination of entangled photons must be over space and be nonlocal.

4.3. Entanglement summary

Interpreting photon spin coordination as nonlocal is a consequence of a series of wrong assumptions. First, the photon is seen as a unitary object operating in space, whereas the photon actually has two identities with its essential one residing in time thereby: 1) exempting it from space travel; and 2) permitting spin coordination to be local in time. Second, photon reception events are taken as marking the endpoint of a particular photon's space path. *This is to assign the **space** location of an event (photon reception) back on to an entity (photon energy) that never had a space location* (see Appendix).

Photon wave-particle duality is currently regarded as a feature of reality and not as a defect in our knowledge. This leaves physicists free to invoke that photon "reality" – wave or particle – most suitable to the experiment at hand. Hence, entangled photons are assumed to reside, travel and spin-coordinate within container space; they are regarded as real particles despite all the evidence to the contrary. Constructing an interpretation based on a flawed assumption is fairly common in the long history of physics.

Photon spin coordination is time-container, energy physics; it is not space-container, particle physics. Einstein was right, his critics wrong. There is no "spooky action at a distance" because with photon energy residing in time there is no spin coordination distance.

5. Conclusions

What dualism, constant velocity and nonlocality have in common is: the application of familiar space-container physics (mechanics) to a time-container realm, namely radiation.

The Quantum Revolution (1900–1928) plus relativity changed less than we think. Classical physics treated time as a second-class dimension unable to host any entities of its own. Nothing has changed in this regard; time is still seen as merely a marker for rest mass movement in space (mechanics). Acknowledging that time can be a container for the energy created by work done on a charge constitutes a big challenge. But the concept that photon energy resides in time, while photon probability-of-reception waves travel

[2] Two more signs that photon energy resides in time: 1) the nonlocal collapse of space-dispersed photon probability waves: such space-progressing waves only occur and their dependence upon orthogonal, time-residing, occurring photon energy allows for space-wide collapse; and 2) photon entanglement and spin coordination make sense if both take place in time, not in space.

space, carries real benefits.

5.1. Photon dualism

With photon energy in time being orthogonal to rest mass in space, the only way the two can interact is via an event (reception) discrete in both space and time. Photons don't "impact," they are not particles and there is no dualism except the one we invent.

5.2. Constant speed of light

With photon energy in time, a photon's immaterial, collapsible waves have a velocity of their wavelength times their frequency. Our movement relative to the light source changes wavelength and frequency inversely; their product, phase velocity, remains the same. A postulate is unnecessary.

5.3. Nonlocality

Entangled photons have their energies bonding in the time dimension and that is where spin coordination takes place. There is no nonlocal spin coordination over space. Einstein's instincts were correct, as usual.

Trying to interpret massless radiation within particle-centric, space container physics (mechanics) has been a failure we refuse to recognize. We have covered up our failure with a variety of make-shift concepts and assertions. For the photon's dualism, we invoke either particle or wave as convenient and ignore the inconsistency; for the constant velocity of light, we resort to a postulate to end discussion; and for entangled photons appearing to coordinate their spins nonlocally over space, we accept it as a curious, acausal, brute feature of reality that contradicts both causality and realism [6].

But physicists have grown comfortable with these make-shift justifications. And the reality we all see and touch is that of space container physics; time container physics is an abstraction. Without a decisive experiment in its favor, time container physics remains a tough sell. As Abraham Pais writes, "*Like most of humanity, physicists tend to cling tenaciously to what they know or think they know, and give up traditional thinking only under extreme duress* [7, p. 137]."

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Appendix

I. The symmetry of mass and energy entities

Entities in general have an essential identity (rest mass or energy) residing in one dimension and a potential, probabilistic identity progressing in the opposite dimension. For the photon its essential identity is energy in time while its potential identity progresses in space enabling diffraction and termination (reception). Rest mass particles have the same identities – essential and potential – but dimensions are reversed.

Rest mass particles decay; some very quickly (the muon), some are slower (carbon-14), while others (the electron) are so slow their decay can only be estimated. Particle decay means that rest mass is active, not passive, in the time dimension. A particle's essential identity, rest mass, resides in space while its potential identity progresses in time enabling eventual termination (decay). A particle is like an alarm clock. The latter has an essential identity you can see and touch; it also has a potential, active identity progressing in time toward termination (of your sleep). Both identities are real and function in their own dimension.

Termination of space container entities (particles) and termination of time container entities (photon energies) are inversely related: particles operate with mass in space; photons with energy in time. Even "termination" is inverted: particle termination (decay) has rest mass emitting (converting to) radiation energy, while photon termination (reception) has rest mass absorbing radiation energy.

Particles entangle in space and progress and terminate over time. Photons entangle in time and progress and terminate over space.

II. Entanglement: mass in space and energy in time

A lead isotope, ^{210}Pb, decays with a half-life of about 22 years. Assume that two of these inertial isotopes are space-adjacent and bond (entangle) in space while progressing (persisting) in time toward decay. One isotope terminates (decays) at 20 years and the second one at 30 years. If you conclude from this that the two space-residing isotopes are separated by 10 years, you are conflating temporal decay event separation with spatial particle separation. This mistake is to take a termination event's location in time and

project it back on to an entity (an isotope) that by residing in space never had a defined time location. The two isotopes have a defined space location relative to some arbitrary reference; but they have no defined time location (position); only their termination events have a defined time location.

The case is the same with two photons whose energies are bonded (entangled) in time. Each photon has a (waveform) potential identity following all (available) space paths and these (potential/collapsible) waves govern photon reception (termination). If two bonded photons are separately received by observers a million kilometers apart, it is photon potential waves that have traversed this space, not time-residing, entangled photon energies. Hence, it is a mistake to say that the two "photons" are a million kilometers apart, as if the photons are unitary, space-progressing objects. This is to take a termination event's location in space and project it back on to an entity (photon energy) that by residing in time never had a defined space location.

Of a photon's two identities one, energy, is never in space; the other, waves of probable reception, follow all available paths and collapse upon photon reception. All scientific and popular summaries of nonlocal photon behavior embrace space container physics and thereby implicitly regard entangled photons as unitary objects (particles) whose reception events mark the endpoints of their paths in space. This to imagine photons as bullets somehow coordinating their spin over extended space. Nature is more subtle than that.

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